Passenger Position Selection and Spatial Data Analysis Based on Spatial Perception

Jiaxin Sun, Dan Wang*

School of Art and Design, Dalian Jiaotong University, Dalian, Liaoning 116028, China

*Corresponding author: 1361782184@qq.com

Abstract. To address passenger crowding and uneven spatial utilization in metro carriages during peak hours, this study investigates B-type metro carriages and examines passenger location choice behavior from a spatial perception perspective. Based on spatial perception theory and ergonomics, a "spatial perception–behavioral response–spatial competition" framework is proposed. Questionnaire surveys and SPSS statistical analysis were used to evaluate passengers' perceptions of efficiency, comfort, and safety across different carriage areas. The results indicate that passenger location choice exhibits significant spatial clustering. Door-adjacent areas show an efficiency-oriented tendency, whereas middle-carriage areas demonstrate higher comfort and safety perception. Spatial facility configuration, handrail arrangement, and buffer space significantly affect regional preference, among which comfort perception is the most influential factor. The findings suggest that passenger location choice is essentially a dynamic trade-off among efficiency, comfort, and safety under limited spatial resources. The findings may provide empirical support for future human-centered metro carriage design and spatial optimization in high-density urban rail transit systems.

Keywords: spatial behavior research,data analysis,ergonomics,subway carriage, spatial perception.

1 Introduction

With the continuous growth of urban rail transit passenger flow, metro carriages during peak hours commonly experience problems such as spatial congestion, passenger crowd aggregation, and declining comfort, particularly reflected in the excessive concentration of passengers near door areas and the imbalance in the utilization of interior carriage space. These issues not only affect operational efficiency but also reduce passengers' travel experience.

Despite extensive studies on metro carriage layout optimization, limited research has quantitatively examined the dynamic relationship between spatial perception and passenger standing behavior under high-density conditions.

At present, urban rail transit systems in China mainly adopt Type A and Type B carriages. Compared with Type A carriages, Type B carriages, due to their flexible

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train formation, widespread application, and higher passenger density per unit space, are more likely to generate typical spatial aggregation phenomena and can better reflect the characteristics of passenger spatial behavior in high-density rail transit environments. Therefore, this study selects the Type B carriage as the research object.

Based on the limitations of existing studies, this research introduces a "spatial perception–behavioral response–spatial competition" analytical framework to explain the dynamic mechanism underlying passenger location choice in high-density metro environments. Unlike traditional static spatial optimization studies, this research quantitatively examines how passengers balance efficiency, comfort, and safety perception under limited spatial resources. Through questionnaire surveys and statistical analysis, the study further explores the interaction between spatial facility configuration and passenger behavioral preference, thereby providing a data-driven reference for metro carriage spatial optimization.

2 Theoretical Foundations and Related Research

2.1 Behavior Guidance Theory

Behavioral Guidance Theory emphasizes that spatial environments guide individual behavior through structural layouts and facility configurations. In recent years, research on rail transit spaces have increasingly adopted data-driven and quantitative approaches to analyze passenger behavior.Yang[1]established an evaluation framework for passenger behavior before and after boarding as well as carriage design preferences, and pointed out that door locations, seat layouts, and handrail facilities are important factors influencing passengers' spatial behavior.

In addition, Xue et al.[2] proposed a data-driven method for identifying behavioral changes. Through dynamic prediction and behavioral deviation detection, they revealed that passenger behavior in high-density rail transit environments exhibits significant dynamic variation characteristics. This indicates that passengers' location selection is no longer merely a problem of static spatial preference, but rather a dynamic behavioral process jointly influenced by spatial perception, environmental pressure, and behavioral competition.

2.2 Ergonomics Theory

Ergonomics emphasizes the adaptive relationship between humans and spatial environments. In metro carriage studies, spatial layout and facility configuration are closely associated with passenger behavior and spatial perception.He et al.[3] pointed out that the configuration of handrail facilities, standing support forms, and buffer spaces in the middle areas of carriages have direct effects on passengers' perceptions of safety and comfort. Through experimental research, Seriani et al.[4] found that different seat layout configurations significantly influence passengers' spatial movement paths and interaction behaviors, thereby further altering the internal density distribution of the carriage. Song N et al.[5], through a multidimensional data fusion model, verified the significant influence of spatial layout and facility configuration on passengers' travel experience.

Behavioral Guidance Theory proposes that spatial structures and facility layouts can guide individual behavior, while ergonomics emphasizes the adaptive relationship between humans and spatial environments. Existing studies have shown that door locations, handrail facilities, and spatial density significantly influence passenger behavior and spatial experience.

Although existing studies have demonstrated the influence of spatial layout and facility configuration on passenger behavior, most research primarily focuses on static spatial optimization or isolated behavioral factors. Limited attention has been paid to the dynamic interaction among spatial perception, environmental pressure, and passenger competition under high-density conditions. Therefore, this study integrates Behavioral Guidance Theory and Ergonomics Theory to construct a spatial perception-based behavioral analysis framework. The framework emphasizes that passengers continuously adjust their standing positions according to perceived efficiency, comfort, and safety, ultimately leading to differentiated regional aggregation characteristics within metro carriages(Figure 1).

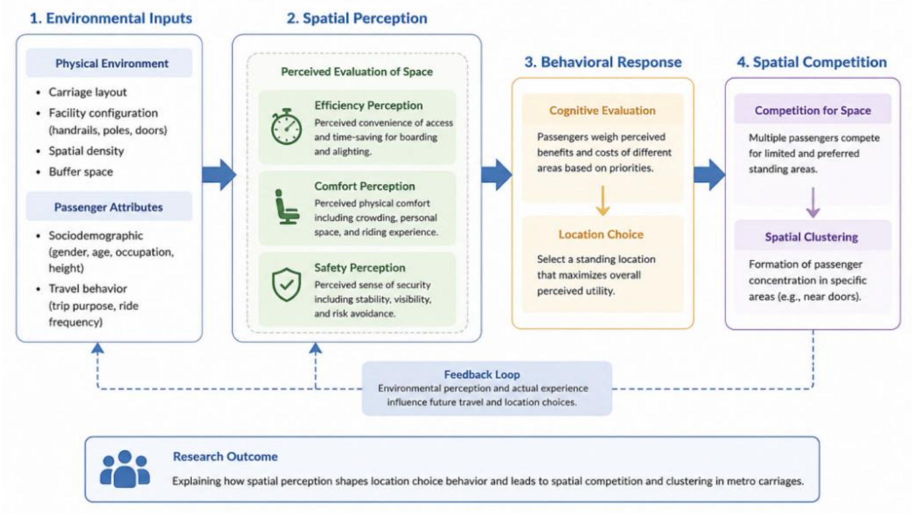

Fig. 1. Research Model of Passenger Location Choice in Metro Carriages

3 Methods

3.1 Questionnaire Design

Based on the "spatial perception–behavioral response–spatial competition" framework, a structured questionnaire was developed covering demographic attributes, spatial facility variables, and psychological perception variables. Demographic variables included gender, age, occupation, height, and metro riding frequency, while spatial variables involved carriage location, handrail accessibility, column distribution, and buffer-space characteristics. Psychological perception variables included crowding, comfort, safety, and fairness.

Behavioral outcome variables were categorized into regional preference degree and functional choice preference. The former describes passengers' tendencies to select specific standing areas, whereas the latter reflects preferences for particular spatial functions, such as transfer efficiency or comfort-oriented environments.

Handrail facilities were defined as accessible support structures, including vertical poles and overhead handrails, whereas buffer spaces referred to relatively open standing areas with lower pedestrian interference. A total of 192 questionnaires were distributed through online and offline surveys, among which 178 valid responses were obtained, yielding an effective response rate of 92.7%. The questionnaire showed satisfactory reliability (Cronbach's $\alpha = 0.842$). Most respondents were frequent metro users aged 20–35 years, primarily office workers and students, which generally reflects the demographic characteristics of peak-hour urban rail passengers.

3.2 Analysis of Spatial Perception Evaluation

With reference to existing studies on carriage layout studies[6](Figure 2), the Type B metro carriage was divided into Areas A, B, C, D, and E (Figure 3),and analyzes the spatial perception characteristics across different regions (Figure 3 and Table 1).

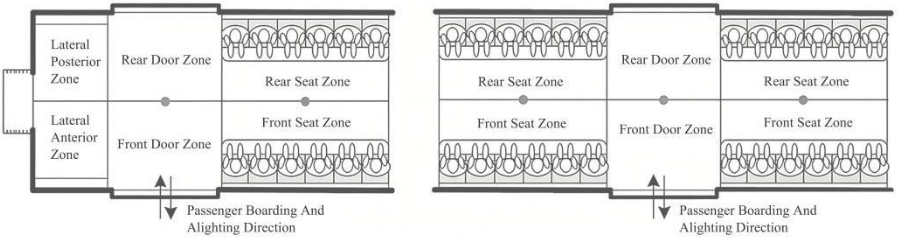

Fig. 2. Carriage Layout and Regional Division. Source: Research on Passengers' Standing Position Choice Behavior in Metro Carriages[6]

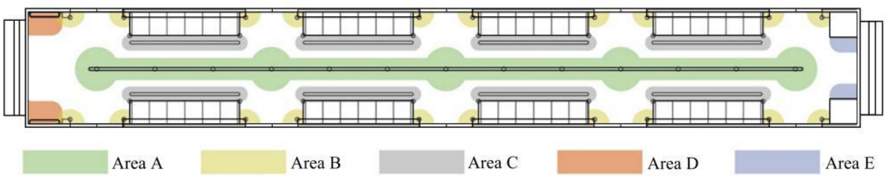

Fig. 3. Division of Passenger Standing Areas

Table 1. Mean Evaluation Results of Spatial Perception in Different Standing Areas

Area	Efficiency $\bar{x}$	Safety $\bar{x}$	Comfort $\bar{x}$	Overall Preference
Area A	4.58	2.27	2.41	3.09
Area B	3.91	3.36	3.18	3.48
Area C	2.83	3.94	3.79	3.52

Area D	3.37	4.31	4.18	3.95
Area E	2.96	3.58	3.47	3.34

Note: $\bar{x}$ represents the arithmetic mean of the corresponding dimension, reflecting passengers' overall evaluation level of the area.

As shown in Table 1, significant spatial differences were observed in passengers' perception across standing areas. Area A exhibited the highest efficiency perception due to proximity to boarding and alighting flows, whereas Areas C and D showed higher comfort and safety perception. These results indicate that passenger location choice is driven not only by efficiency, but by a trade-off among circulation convenience, interpersonal distance, and environmental stability. Areas with lower crowd interference and higher spatial openness tend to generate stronger and more stable standing preferences.

3.3 Analysis of Factors Affecting Regional Preference Degree

A chi-square test was conducted to analyze the associations among different variables(Table 2), with the significance level set at α = 0.05.

Table 2. Chi-square Test Analysis of Preference Degree for Different Standing Areas

	Area A		Area B		Area C		Area D		Area E	
	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Gender	6.428	0.093*	4.173	0.384	10.917	0.012**	12.684	0.005**	3.621	0.458
Age	15.384	0.081*	9.618	0.382	18.507	0.029**	21.274	0.011**	7.941	0.541
Profession	12.706	0.048**	16.915	0.009**	22.364	0.001**	19.507	0.003**	11.473	0.176
Height	8.241	0.221	13.574	0.035**	17.923	0.008**	20.684	0.002**	10.231	0.114
Riding Frequency	9.584	0.143	14.806	0.022*	8.372	0.211	10.472	0.106	5.863	0.439
Columns	22.481	0.000**	12.307	0.071*	27.618	0.000**	30.942	0.000**	7.408	0.286
Handrail facilities	18.932	0.001**	7.584	0.268	23.814	0.000**	25.271	0.000**	5.308	0.381
Buffer Space	21.364	0.000**	15.742	0.014**	14.268	0.028**	11.638	0.069*	6.174	0.291

Note: "**" indicates significance at the 95% confidence level ($P < 0.05$); "*" indicates significance at the 90% confidence level ($P < 0.10$).

The chi-square analysis showed that spatial facility variables, including handrail accessibility, column distribution, and buffer-space configuration, had stronger associations with regional preference than demographic variables. Areas with greater support accessibility and lower pedestrian interference were more likely to attract stable passenger aggregation, indicating that passenger standing behavior is primarily influenced by spatial perception and facility configuration under high-density conditions.

3.4 Analysis of Variance and Regression Analysis

One-way ANOVA results demonstrated significant differences in passengers' comfort perception across different standing areas ($p < 0.001$), indicating that spatial location significantly affects passengers' environmental evaluation. Middle-carriage areas generally received higher comfort and safety scores, whereas door-adjacent areas were associated with stronger crowding perception due to intensive passenger circulation.

Pearson correlation analysis further revealed that crowding perception was negatively correlated with regional preference, while comfort and safety perception showed significant positive correlations. Regression analysis confirmed that comfort perception was the strongest predictor of passenger location choice behavior. This finding suggests that, under high-density travel conditions, passengers tend to prioritize environmental stability and psychological comfort over purely efficiency-oriented spatial choices.

3.5 Discussion

The results indicate that passenger standing behavior is jointly influenced by mobility efficiency and psychological perception. Door-adjacent areas improve boarding and transfer efficiency but reduce comfort and environmental stability due to intensive passenger circulation. In contrast, middle-carriage areas provide more stable standing environments with lower interference intensity, resulting in stronger spatial preference.

Moreover, the significant effects of handrail accessibility and buffer-space configuration suggest that passengers prioritize physical stability and controllable interpersonal distance under high-density conditions. Therefore, passenger location choice can be regarded as a perception-driven dynamic competition process shaped by spatial facility configuration and environmental pressure.

4 Conclusion

This study investigates passenger location selection behavior in Type B metro carriages from the perspective of spatial perception and data-driven behavioral analysis.

Compared with traditional experience-oriented carriage studies, this research establishes a quantitative analytical framework linking spatial perception and passenger behavioral response. The study not only reveals the dynamic competition mechanism underlying passenger location selection, but also provides empirical evidence for optimizing spatial facility distribution in metro carriages. The findings may contribute to future human-centered metro carriage design and data-driven spatial optimization strategies in high-density urban rail transit systems.

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